MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2017/18

ENT3036 – SEMICONDUCTOR DEVICES

(NE)

17 MAR 2018
2.30 pm – 4.30 pm
(2 Hours)

INSTRUCTION TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.
2. Answer all the questions and all the questions carry equal marks of 25. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) A silicon pn junction at zero bias has dopant concentrations of $N_a = 10^{17}$ cm^{-3} and $N_d = 5\text{x}10^{15}$ cm^{-3}. Temperature T = 300 K.

(i) If the Fermi levels in n-side and p-side are given by

$$E_F - E_{Fi} = kT\ln\left(\frac{N_d}{n_i}\right) \text{ and } E_{Fi} - E_F = kT\ln\left(\frac{N_a}{n_i}\right)$$

where $n_i = 1.5\times10^{15}$ cm^{-3} and $k = 8.62\times10^{-5}$ eV/K, calculate Fermi levels on p-side and n-side, and obtain the built-in potential. [2+2+1 marks]

(ii) Calculate the space charge widths in n- and p-sides, respectively:

$$x_n = \left[\frac{2\varepsilon_S(V_{bi}+V_R)}{e}\left(\frac{N_a}{N_d}\right)\left(\frac{1}{N_a+N_d}\right)\right]^{1/2} \text{ and } x_p = \left[\frac{2\varepsilon_S(V_{bi}+V_R)}{e}\left(\frac{N_d}{N_a}\right)\left(\frac{1}{N_a+N_d}\right)\right]^{1/2}$$

[2+2 marks]

(iii) Based on information obtained from above calculations, sketch and name the type of pn junction. [2+2 marks]

(b) With aid of diagrams, briefly explain minority carrier distributions for a npn operating in the:
(i) cutoff mode, and [3 marks]
(ii) inverse-active mode. [3 marks]

(c) The emitter current (I_E) for an npn bipolar junction transistor (BJT) is measured and is found to be 1.2 mA, the collector is given by

$$I_C = \frac{eD_nA_{BE}}{x_B}\times n_{B0}\exp\left(\frac{V_{BE}}{V_t}\right) \quad \text{and} \quad I_S = \frac{eD_nA_{BE}}{x_B}\times n_{B0}$$

Calculate the base-emitter voltage, $V_{BE} = V_t\ln\left(\frac{I_C}{I_S}\right)$ with the following parameters.

Common-emitter current gain, β	150
Cross-sectional area of the base emitter junction, A_{BE}	1.4×10^{-3} cm^2
Neutral base width, x_B	0.70 μm
Thermal-equilibrium electron concentration in the base, n_{B0}	2.3×10^3 cm^{-3}
Minority carrier electron diffusion coefficients in base, D_n	19 cm^{2}s^{-1}

[6 marks]

Continued ...

Question 2

(a) (i) By means of a simple diagram describe the basic operation of a n-channel pn junction JFET. Briefly explain the pinchoff effect on the I-V characteristic.

[3+2 marks]

(ii) Consider an n-channel single-gate silicon JFET at T = 300 K with impurity doping concentrations of $N_D = 4\times10^{16}\,cm^{-3}$ and $N_A = 5\times10^{18}\,cm^{-3}$. The channel thickness is 0.35 μm and the internal pinchoff voltage (V_{po}) is given by

$$V_{po} = \frac{ea^2N_d}{2\epsilon_s}$$

where a is the channel thickness, e (1.6×10^{-19}C) is the electronic charge and ϵ_s ($11.7\times8.85\times10^{-14}$ F/cm) is the permittivity of the semiconductor. Calculate the internal pinchoff voltage and the pinchoff voltage. [3+3 marks]

(b) (i) Consider a uniformly doped n-channel silicon JFET with the following parameters: $N_A = 10^{19}\,cm^{-3}$, $N_D = 3\times10^{16}\,cm^{-3}$, $a = 0.40$ μm and μ_n = 1000 cm^2/V-sec. The maximum drain to source voltage is to be 5V. When V_{GS} = 0, the effective channel length L', is to be 90 percent of the original channel length. Determine L.

[10 marks]

(ii) Name and briefly explain TWO (2) nondeal effects that could occur in JFET.

[2+2 marks]

Continued...

Question 3

(a) Draw the energy-band diagrams of metal oxide semiconductor (MOS) capacitors with *p*-type substrate to explain the accumulation, depletion and inversion in the structure for:
  (i) a positive gate bias,
  (ii) a moderate negative gate bias and
  (iii) a large negative gate bias [3 ×2 marks]

(b) State the definition of the followings for a MOS capacitor:
  (i) Flat band voltage (V_{FB})
  (ii) Threshold voltage (V_{TN}) [2 ×1marks]

(c) Consider a MOS capacitor with p-type silicon substrate doped at $N_a = 10^{15}$ cm^{-3}, a silicon dioxide insulator with a thickness of t_{ox} = 12 nm and an aluminum gate. The flat band voltage is given by

$$V_{FB} = \phi_{ms} - Q'_{ss}/C_{ox}$$

where the C_{ox} is the oxide capacitance, Q'_{ss} is the oxide trapped charges, and ϕ_{ms} is the work function between the metal and silicon. $Q'_{ss} = 10^{10}$ e-charges/cm^{-3} and work function ϕ_{ms} = -0.88 V.
  (i) Calculate C_{ox}, Q'_{ss} and obtain V_{FB}.
  (ii) Given x_{dT} (the maximum space charge width) is 8.63 ×10^{-5} cm, calculate ϕ_{fp} (the potential between E_{Fi} and E_{Fp}), Q'_{SD}(max) (the maximum space charge in the depletion region) and obtain the threshold voltage V_{TN}.
[3 + 5 marks]

(d) (i) With a proper diagram, explain how the MOS with p-type substrate is used in a Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET). [5 marks]

(ii) An ideal n-channel MOSFET is operated with the following parameters: channel length L =1.5 μm, electron mobility μ_n = 650 cm^2/V-s, and oxide thickness C_{ox} = 7 ×10^{-8} F/cm^2, and threshold voltage V_T = 0.65 V. What should be the channel width such that I_D (sat) = 5 mA for V_{GS} = 5 V? [4 marks]

Continued ...

Question 4

(a) (i) With aid of band diagram, explain how the negative differential resistance occurs in Gunn diode. [2 marks]

(ii) What is the difference between Zener tunnel diode and Gunn diode in term of electron transport phenomenon? [3 marks]

(iii) What are the advantages and disadvantages of Gunn Diode? [4 marks]

(b) (i) With the aid of a diagram, design mm-wave co-axial cavity Gunn oscillator. Show that the oscillator frequency is given by

$$f_n = \frac{cn}{2l}$$

where l is the cavity length, c the speed of light and n is the number of half of the cavity. [8 marks]

(c) (i) Sketch the structure of an Ionization Avalanche Transit-Time (IMPATT) diode and oscillator circuit required for its operation. [4 marks]

(ii) An IMPATT diode has intrinsic region length at 3.0 μm with holes drift velocity of 9.1×10^8 cms^{-1}; calculate the optimum operating frequency for the diode. [4 marks]

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PHYSICAL CONSTANTS:

Thermal voltage:	$V_t = 0.0259$ V
Intrinsic concentration of Silicon at 300K:	$n_i = 1.5\times10^{10}$ cm^{-3}
Intrinsic concentration of Silicon at 373K:	$n_i = 2.5\times10^{12}$ cm^{-3}
Intrinsic concentration of Gallium Arsenide at 300K:	$n_i = 1.8\times10^{6}$ cm^{-3}
Boltzmann's constant:	$k = 1.3806\times10^{-23}$ J/K
Electronic charge:	$e = 1.6\times10^{-19}$ C
Permittivity of free space:	$\varepsilon_0 = 8.85\times10^{-14}$ F/cm
Dielectric constant of Silicon at 300K:	$\varepsilon_r = 11.7$
Dielectric constant of Silicon oxide at 300K:	$\varepsilon_i = 3.9$
Dielectric constant of Gallium Arsenide at 300K:	$\varepsilon_{GaAs} = 13.1$

End of paper.